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HZB Helmholtz Zentrum Berlin bERLinPro

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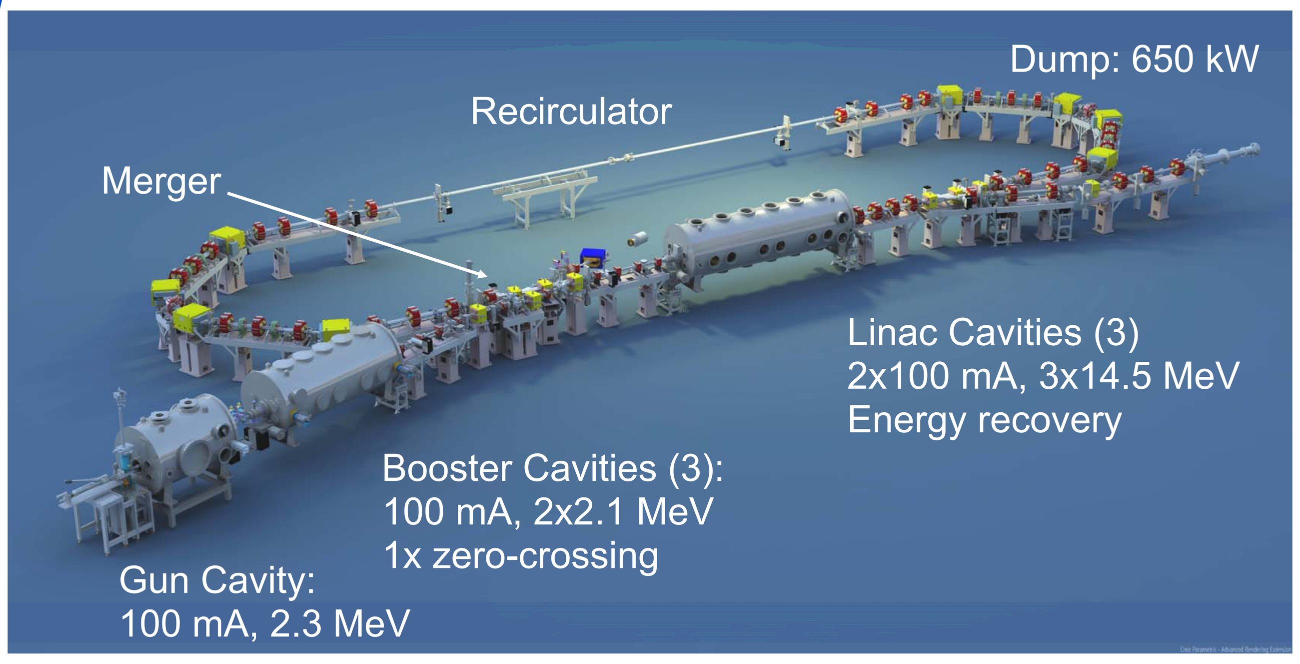
Update on SRF Cavity Design, Production and Testing for bERLinPro

bERLinPro Energy Recovery Project



According to their role the cavity types for bERLinPro need to meet varying requirements, see table

bERLinPro's main **goal** is the ERL operation of a **low emittance, high current beam** (ε_n < 1 mm mrad, I = 100 mA).
Its basic concept starts with a 6.5 MeV injector consisting of a 1.4·λ/2 cell SRF gun followed by a booster section with three 2-cell-cavities. The beam is merged into the main linac via a dogleg merger and accelerated by three 7-cell SC cavities to 50 MeV. After the following recirculation via a racetrack shaped return arc, the decelerated beam is dumped in a 650 kW, 6.5 MeV beam dump.

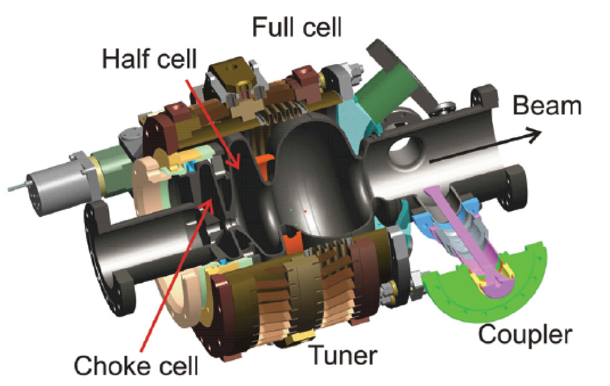
Status of bERLinPro building construction site:

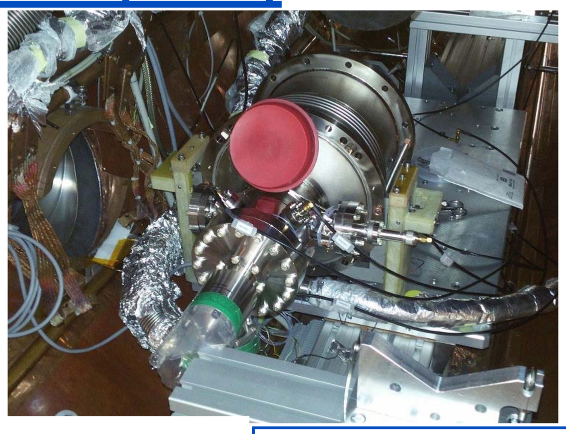
Designed and first measured RF (SRF) properties of the three bERLinPro cavity types

Design Parameter	Gun	Booster	Linac
Type of operation	CW, high beam power, high peak on-axis field	CW, high beam power, intermediate acc. field	CW, high beam current high acc. field
Number of cells	$1.4\times\lambda/2$	$2\times\lambda/2$	$7\times\lambda/2$
$TM_{010\text{-}\pi}$ frequency (MHz)	1300	1300	1300
Operating temperature (K)	1.8	1.8	1.8
Beam current (mA)	100 (4)	100	2× 100
HOM absorber	beam tube	beam tube	waveguide + beam tube
FPC type	twin modified c-ERL (TTF-III)	twin modified c-ERL	single modified TTF-III
Energy gain/cavity (MeV)	2.3 (3.5)	2.1	14.8
Beam emission or RF phase (deg)	40-60	-90 and 0	-15
$R/Q_{\parallel}$ for $\beta = 1$ (Ω)	150 (*132.5*)	219	788
Geometry factor G (Ω)	174 (*154*)	261	266
E_{peak}/E_{acc} [1]	1.45 (*1.66*)	2.02	2.08
B_{peak}/E_{acc} [1] (mT/MVm^{-1})	3.2	4.44	4.40
Q_{loaded} for $TM_{010\text{-}\pi}$	$1.1\cdot10^5$ ($3.6\cdot10^6$)	$1.05\cdot10^5$	$5\cdot10^7$
Max. Q_{ext} 1st TM dipole band	$11\cdot10^3$	170, 7300	$\leq 8\cdot10^3$
$P_{forward}$ at $\Delta f = 0$ (kW)	230 (up to 5.8)	230	1.4
$\Delta f/\Delta P$ (Hz/mbar)	20	5	not calculated yet
Measured Properties with HV	**Gun**	**Booster**	**Linac**
Peak on axis electric field (MV/m)	34.5	34-40	NA
Peak surface electric field (MV/m)	57.3	34.4-40.4	NA
Peak magnetic field (mT)	110.4	75.5-89	NA

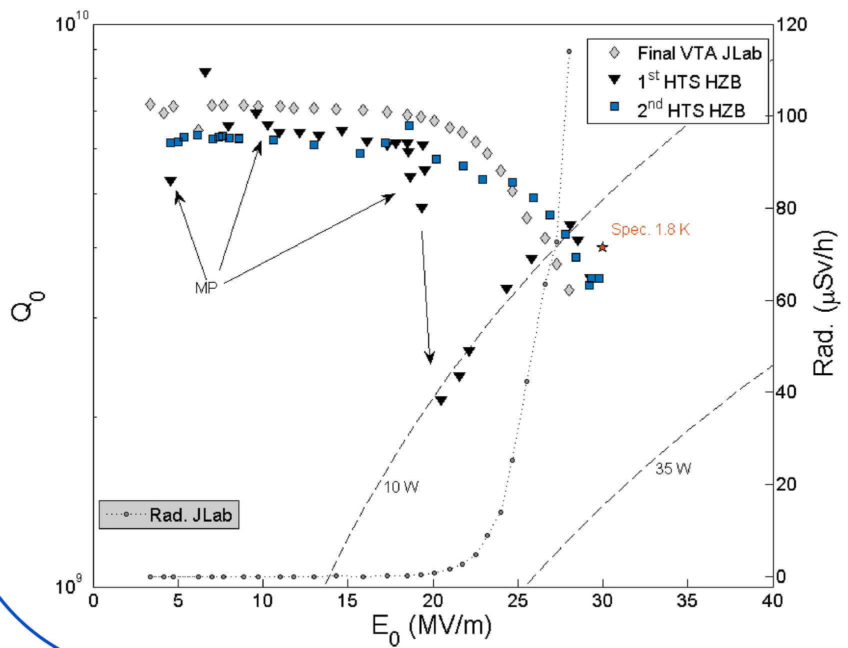
[1] For the Gun cavity this ratio is given for peak surface field to maximum on-axis field.

SC RF Photoinjector (Gun)



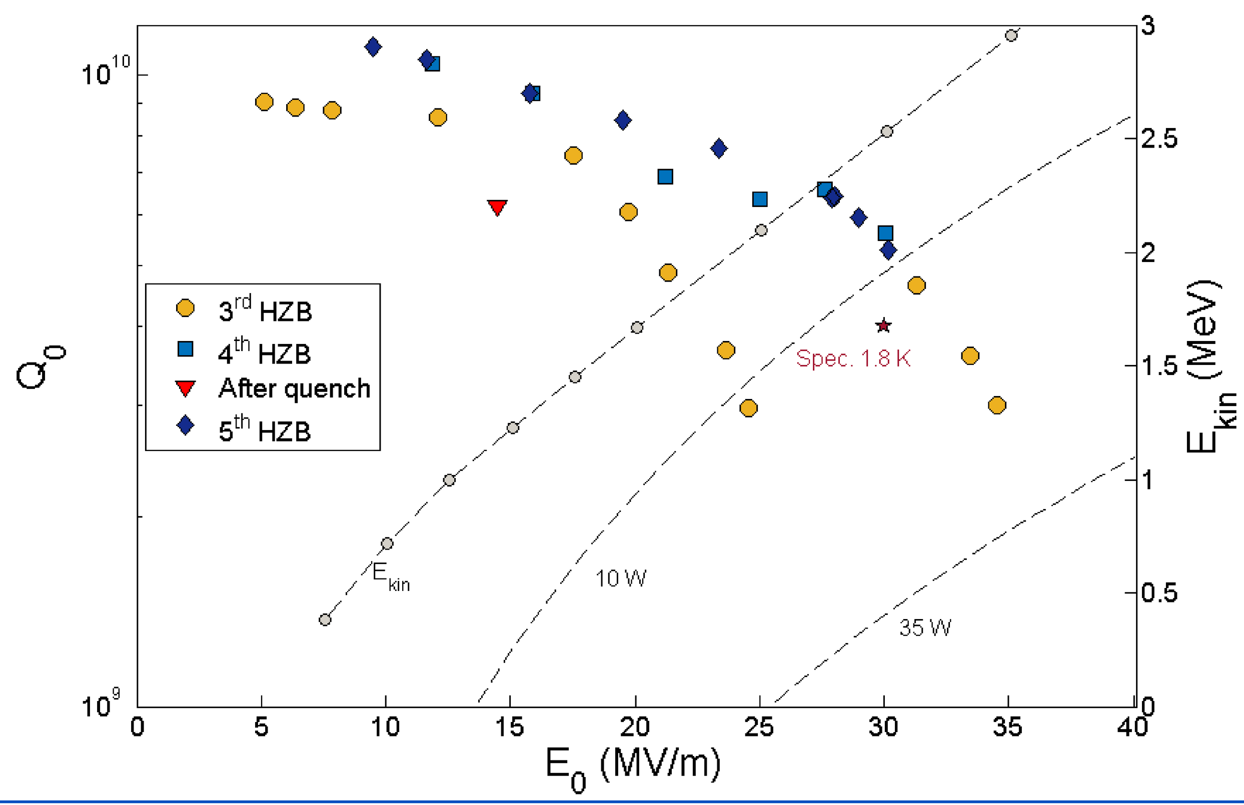


The SRF Photoinjector is a 1.4 cell cavity optimized for high emission phase and peak on-axis longitudinal elecric field close to the cathode within the half-cell. The cathode carrier is a demountable, thermally and electrically isolated stalk on which multi-alkali photocathodes will be deposited, similar to the HZDR system for the 3.5-cell SRF gun at ELBE.
The pictures to the left shows a cross-section of the cavity and the prototype cavity which was manufactured at JLab and installed at HoBiCaT for first horizontal testing.



Last vertical and first horizontal test for Gun 1.0:

- The VTS data was reproduced after a first power rise to process through multipacting barriers (MP)
- As the geometry varied from design, MP was increased as was reconstructed by PIC simulations (see table)



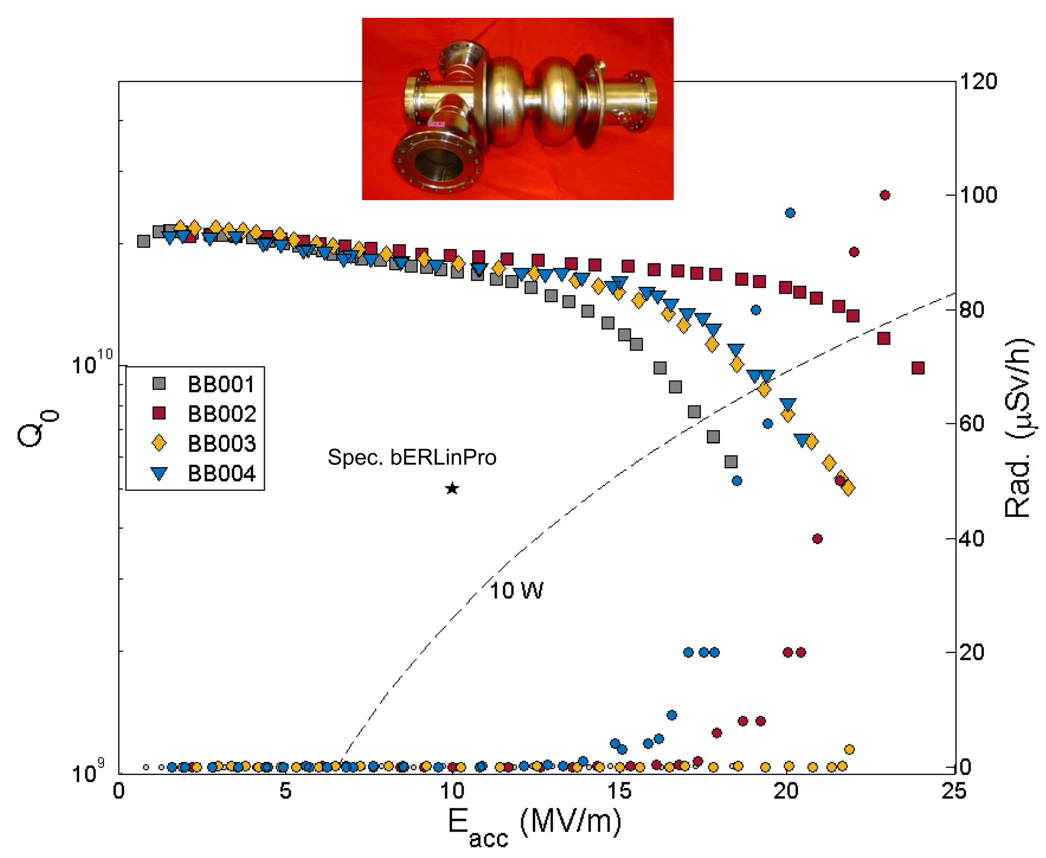
Latest horizontal Q_0 measurements of Gun1.0 at HZB at 1.8 K using critically coupled antennas. For reference the max. energy gain at optimum phase is given.

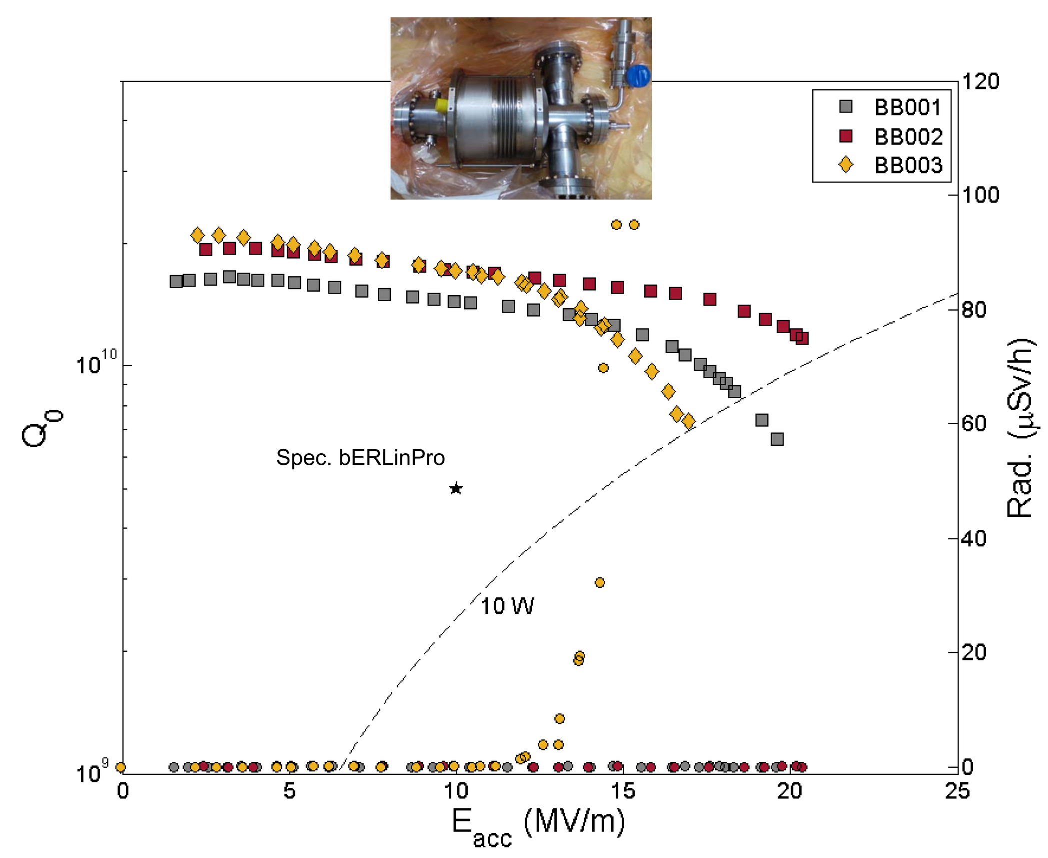
After work on the helium vessel in the workshop a further test was required:

- Unfortunately the cavity was vented by a short vacuum hose being in an undefined state
- First cavity multipacted and eventually quenched at low fields ≤ 0.2 MV/m
- This was overcome by RF processing (yellow dots), where strong radiation and multipacting was observed and finally quenched at 35 MV/m
- The cavity was recoverd by thermal cycle above T_C and regularly achieves the design field and thus the beam energy range of bERLinPro

2-cell Booster Cavity

4 cavities were fabricated, processed and tested at JLab. The design is based on Cornell's booster cavity with a new input coupler section to house a pair of modified KEK c-ERL couplers. The couplers were optimized for low kick and stronger coupling.





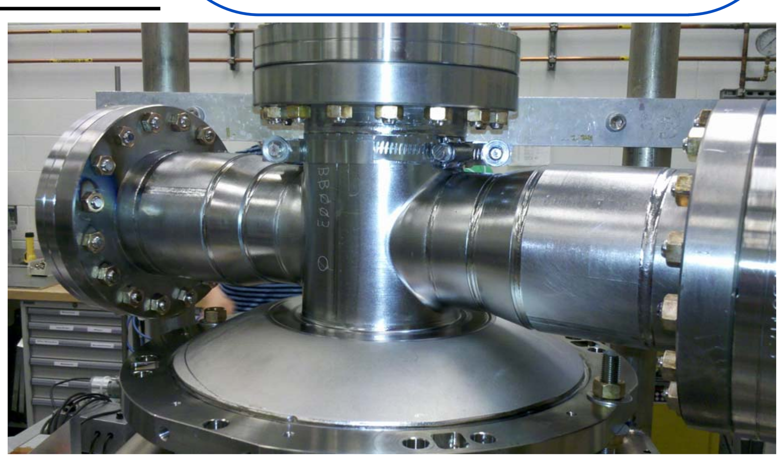
Booster cavity vertical tests at JLab before and after helium vessel welding (except for BB004) at 1.8 K. Due to leakage problems below λ point at the FPC NbTi flanges, cavity BB001 was only measured at 2.0 K.

Mechanical properties

Cavity and set up	$\Delta f/\Delta P$ (Hz/mbar)	$\Delta f/(E_{acc})^2$ (Hz/(MV/m)^2)
Booster		
VTA	-205	-7.1
VTA + HV	-278	-6.5
Simulated VTA + HV	-180	NA
Simulated HV+tuner	≈5	-2.2 [3]
Gun		
VTA	-601	-5.2
VTA + HV	-561	-4.7
Simulated VTA +HV	-550	NA
HV+threaded rods	150	-3.7
Simulated HV+tuner	≈5-10	NA

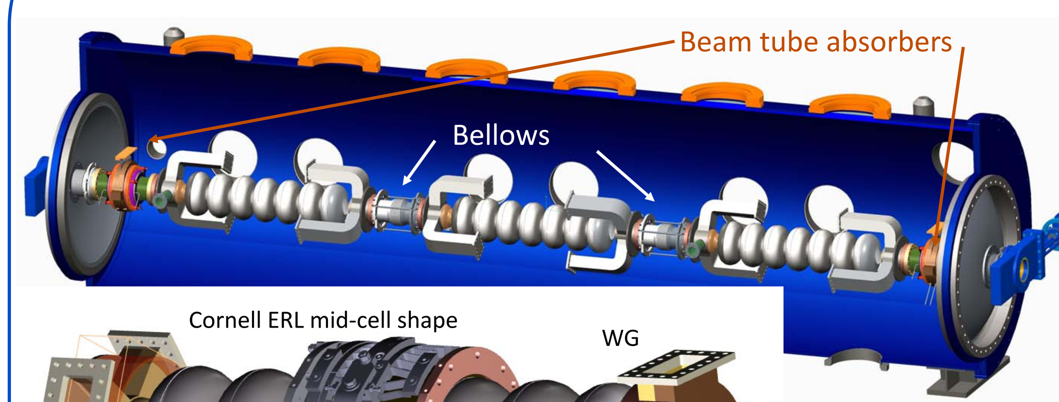
- All cavity types require low helium pressure sensitivity
- The values measured within the unconstrained vertical and horizontal set up were also found by ANSYS simulations
- This gives confidence to achieve the optimized value of the design

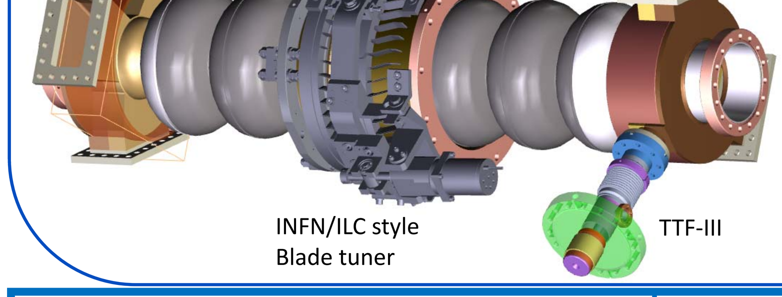
The booster cavities all are beyond specifications.
Field emission onset is above the field level of 10 MV/m for bERLinPro.



Details of the fundamental power coupler port with the tapered outer conductor tube. This section was mainly modified from the Cornell design

7-cell Linac Cavity

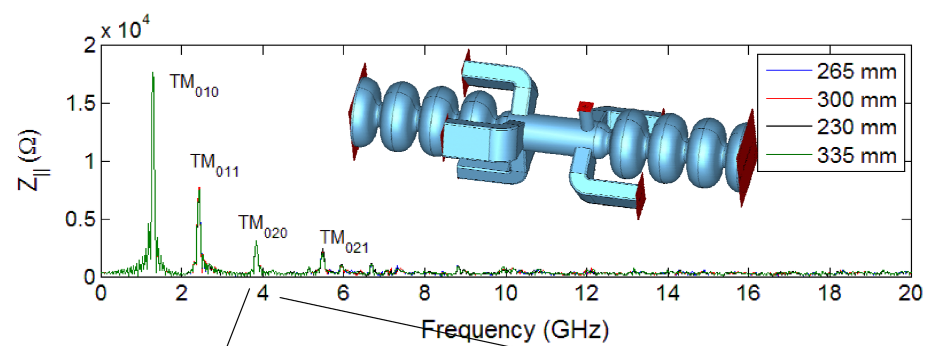


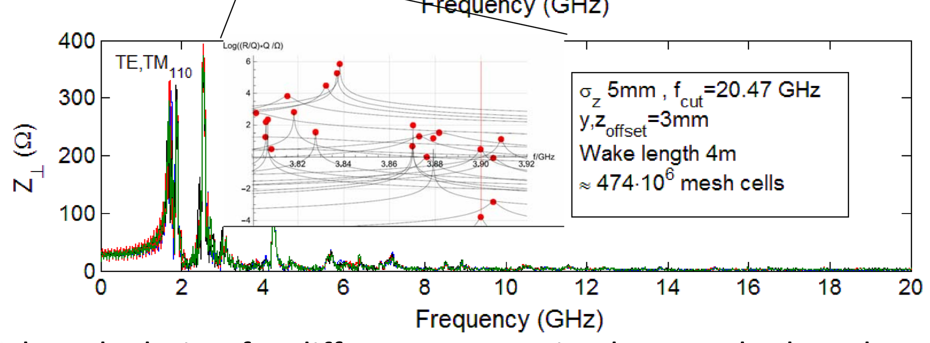


Current draft of the cavity with 5 HOM damping waveguides, 1 coaxial CW modified TTF-III coupler and possible cooling of the ports with the helium vessel

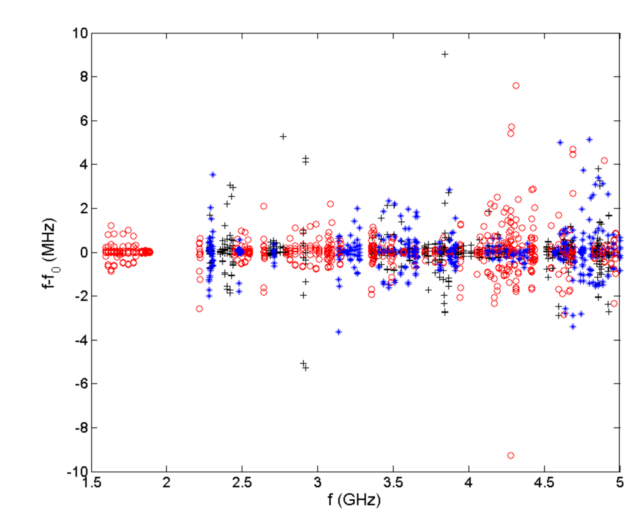
Status: The RF design was completed [6].

- In parallel module design and RF studies of the concatenated 3 cavity string [18] are ongoing. The chain needs to be optimized for best HOM damping performance.
- Module based coupler kick studies for optimum orientation of FPC/waveguides
- First Wake studies done to rule out unwanted modes in beam tube transitions between cavities





Wake calculation for different connecting beam tube lengths. Coupling at beam harmonics needs to be avoided.



HOM frequency variation due to end-cell tuning for field-flat tuned geometries obtained by perturbation method [14, 16]

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